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Feasibility of low radiation dose retrospectively-gated cardiac CT for functional analysis in adult congenital heart disease☆

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ABSTRACT

Background: The use of cardiac computed tomography (CT) in the evaluation of adult congenital heart disease patients is limited due to concerns of high radiation doses. The purpose of this study was to prospectively assess whether low radiation dose cardiac CT is feasible to evaluate ventricular systolic function in adults with congenital heart disease.

Methods: The study group included 30 consecutive patients with significant congenital heart disease who underwent a total of 35 ECG-gated cardiac CT scans utilizing a 320-detector row CT scanner. Each study included a non-contrast scan and subsequent contrast-enhanced retrospectively-gated acquisition. Effective radiation dose was estimated by multiplying the dose length product by a k-factor of 0.014 mSv/mGy cm.

Results: The mean age of the patients was 34.4 ± 8.9 years, 60% were men, and mean body mass index was 24.2 ± 4.3 kg/m^2. A majority of patients (n = 28, 93.3%) had contraindications to cardiac MRI. A tube potential of 80 kV was used in 27 (77.1%) of the contrast-enhanced scans. The mean signal-to-noise and contrast-to-noise ratios were 11.5 ± 3.9 and 10.3 ± 3.7, respectively. The median radiation dose for non-contrast and contrast-enhanced images were 0.1 mSv (0.07–0.2 mSv) and 0.94 mSv (0.5–2.1 mSv), respectively. All 35 CT scans were successfully analyzed for ventricular systolic function.

Conclusions: A low radiation contrast-enhanced, retrospectively-gated cardiac CT with a median radiation dose of less than 1 mSv was successful in evaluating ventricular systolic function in 30 consecutive adult congenital heart disease patients who underwent a total of 35 scans.

1. Introduction

With advancements in pediatric cardiac care, there is a growing population of adults with congenital heart disease [1–5]. Transthoracic echocardiography is the first-line modality for diagnosis and serial assessment in congenital heart disease [6]. However, echocardiographic assessment of cardiac function in adult congenital heart disease can be challenging due to the complex anatomy, limited field of view, and poor echocardiographic windows following cardiac surgeries. Many of these patients have a single ventricle or a morphologic right ventricle that supports the systemic circulation. These ventricles deform under the altered hemodynamics, and functional assessment is critical for clinical care. The complex geometry of a single or right ventricle make accurate measurements of ventricular size and systolic function challenging with echocardiography. Echocardiographic assessments of single or right ventricular size and systolic function have meager reproducibility in congenital heart disease patients [7–8]. Often, only qualitative assessments of systolic function can be made, and volumetric imaging is required [9–10]. Cardiac magnetic resonance imaging (MRI) has been used as a complementary or alternative technique due to the ability to perform volumetric imaging with no ionizing radiation [6,11–12]. However, cardiac MRI may be contraindicated in patients with pacemakers or implantable cardioverter-defibrillators.

The use of cardiac computed tomography (CT) in congenital heart disease patients has been limited due to concerns over high radiation dose and associated cancer risks [13–16]. Cardiac CT has been compared favorably to MRI for ventricular volume and ejection fraction assessments, even among patients with congenital heart disease [17–24]. We hypothesized that a low radiation dose contrast-enhanced,

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retrospectively-gated cardiac CT would be feasible to evaluate ventricular systolic function in adult congenital heart disease patients.

2. Methods

The institutional review board approved this prospective study. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki. All of the subjects provided written informed consent to participate. The study was registered on ClinicalTrials.gov (registration NCT01621594). Inclusion criteria consisted of patients at least 18 years old with congenital heart disease who were clinically referred for contrast-enhanced cardiac CT. Exclusion criteria were pregnancy or renal dysfunction, estimated glomerular filtration rate less than 30 mL/min/1.73 m^2 [25]. Patients were not excluded for weight, heart rate, or heart rhythm.

Overall, 30 consecutive patients underwent a total of 35 CT scans with axial imaging using a second-generation, 320 × 0.5-mm detector row CT unit (Aquilion ONE ViSION Edition; Toshiba Medical Systems, Otawara, Japan) with a gantry rotation time of 275 msec. There were 5 patients with a second CT scan as part of a serial evaluation, not due to an inadequate initial scan. Tube potential and tube current were determined by automatic exposure control (^{SURE}Exposure3D, Toshiba Medical Systems, SD 150 for non-contrast and SD 110 for contrast-enhanced images) on the basis of the X-ray attenuation on scout images and reconstruction kernel [26]. Images were reconstructed with a 512 × 512 matrix, 0.5 mm thick sections, and 0.25-mm increments using kernel FC03, iterative reconstruction AIDR3D standard (Toshiba Medical Systems) [27].

Patients were eligible to receive either metoprolol orally and/or intravenously to reduce the resting heart rate, though the majority did not receive either (n = 27, 77.1%) due to being pacemaker-dependent. An initial non-contrast scan was performed to delineate prior surgical changes and determine the appropriate scan range for the contrast-enhanced acquisition. Typically, Iopamidol (Isovue 370, Bracco Diagnostics, Princeton, NJ; 370 mg of iodine per milliliter) was injected via an antecubital vein at 5 mL/s in a triphasic protocol: 75 mL of contrast followed by 30 mL of a 50% contrast-50% saline mixture and then 50 mL of saline. Breath-held retrospectively-gated contrast-enhanced images were triggered within 1 s of a threshold of 600 Hounsfield units in the left ventricular blood pool using bolus-tracking. If an evaluation for coronary artery disease was requested, patients received 0.4 mg of sublingual nitroglycerin prior to imaging. Effective radiation doses were estimated by multiplying the dose-length product (DLP) reported by the scanner by using a conversion factor of 0.014 mSv/mGy cm according to standard methodology [28]. Ventricular volumes and ejection fraction were quantified from 0.5 mm thick slices using 5% phase increments on a workstation (Vital Images, Minnetonka, MN). Fig. 1 shows an example of a contrast-enhanced CT scan with end-diastolic and end-systolic frames. Cine videos from a contrast-enhanced scan are available in the Supplementary material (Videos 1–3). Data are presented as means ± standard deviations or as median with interquartile range (IQR).

3. Results

In total, 30 patients with congenital heart disease underwent a total of 35 scans from July 2013 to April 2016. Table 1 describes the baseline characteristics of the patients, radiation doses, and image quality. The primary diagnosis for the referred patients were classified as D-transposition of the great arteries (n = 7), atrial or ventricular septal defect (n = 6), Tetralogy of Fallot (n = 5), double outlet right ventricle (n = 5), congenitally corrected transposition of the great arteries (n = 2), single ventricle (n = 2), congenital valve disease (n = 1), Shone's complex (n = 1), or anomalous coronary artery (n = 1). The patient's prior surgeries included atrial switch (n = 7), pulmonary valve replacement (n = 6), ventricular septal defect repair (n = 6), atrial septal defect repair (n = 5), transannular patch repair (n = 5), double outlet right ventricle repair (2 ventricles, n = 5), lateral tunnel Fontan (n = 2), prosthetic aortic valve replacement (n = 2), Ross procedure (n = 2), subaortic membrane resection (n = 1), mitral valve repair (n = 1), and anomalous coronary artery reimplantation (n = 1). The patients were primarily referred for cardiac CT to evaluate for ventricular size and function but additional secondary evaluations included: aortic size, main and branch pulmonary artery stenosis, baffle or Fontan obstructions, coronary artery anastomoses, and atherosclerotic coronary artery disease. The vast majority of patients (n = 28, 93.3%) had contraindications to cardiac MRI due to pacemaker/implantable cardioverter-defibrillator (n = 27) or breast tissue expander (n = 1). The remaining two patients were referred in part for coronary artery disease evaluation.

The mean age was 34.4 ± 8.9 years (range 22–50 years) and 60% (n = 18) were men. The mean body mass index (BMI) was 24.2 ± 4.3 kg/m^2. Overall, 15 patients were overweight (n = 13, 43.3%) or obese (n = 2, 6.7%). Only 8 patients (22.9%) received metoprolol, oral or intravenous, prior to the CT scan. The mean heart rate during the contrast-enhanced retrospectively-gated acquisition was 61.1 ± 6.6 bpm.

A tube potential of 80 kV was used in 27 of the scans (77.1%) while a tube potential of 100 kV was used in the remaining 8 scans (22.9%). On the contrast-enhanced images, the mean signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were 11.5 ± 3.9 and 10.3 ± 3.7, respectively. The median radiation dose for non-contrast scans was

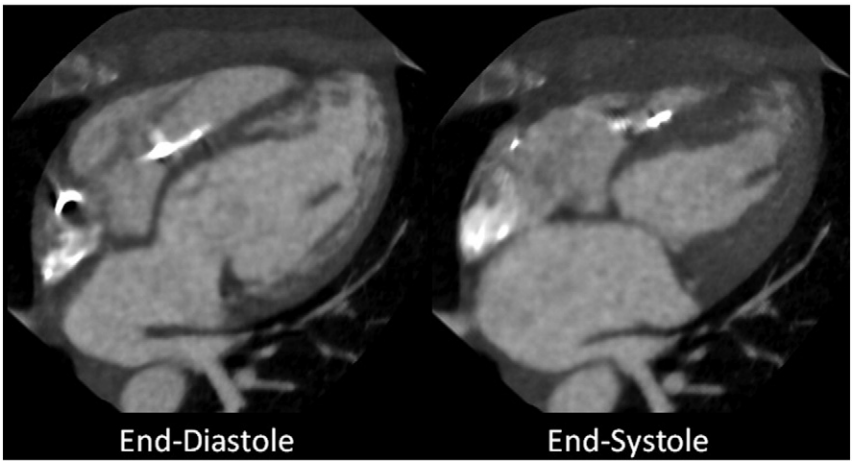

Fig. 1. 46 year old (BMI 19.6) with congenitally corrected transposition of the great arteries, complete heart block with dual chamber pacemaker and inadequate echocardiographic windows. Four-chamber view demonstrating typical image quality at end-diastole and end-systole with an effective radiation dose of 0.27 mSv.